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FENCE DETECTION SYSTEM.(U)

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in a specific area, be consulted as to the required depth for a good earth ground. In addition, the outer shield of the MILES should also be fastened to the rod using the shortest route possible.

It is also recommended that the transducers be tied more securely to the fence fabric, thus eliminating the transmission of an external stimulus directly to the transducer rather than through the fence and into the transducer. The 2D installation had transducers tied at approximately 2 foot intervals allowing portions of the transducer to bow away from the fence. Transducers were secured at 4 to 8 inch intervals and additional wind data collected appeared more representative of the fence.

The coiled barbed tape at the top is a definite asset in improving detection capability in a fence detection system. Relating observation of the test scenario with transducer outputs, it becomes apparent the deterrent of barbed tape increases the chance of a detection by increasing the time for an intruder to go over, thus causing greater gyration of the fence. Any detrimental effects such as vibration from wind whistling through the tape appeared minimal.

In relation to the actual scenarios, it is felt that the Special Forces tests were more representative of actual penetrations than many of the "simulated" scenarios. Hence, it is suggested that "Special Forces type" tests also be emphasized in future testing.

APPENDIX A

The Principles of Operation of the MILES and EWIT Transducers in Fence Mounted Applications

by

William C. Fullin

Working Paper #3

Pattern Analysis & Recognition Corp.

Rome, New York 13440

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I INTRODUCTION

The purpose of thes report is to provide a qualitative understanding of the behavior of the MILES and EWIT transducers when used in a fence mounted application. This information should prove useful in the design of any intruder detection logic package which may be used with these devices.

The system which is to be considered here consists of a standard chain-link fence to which would be attached.the MILES or EWIT transducers. For purposes of analysis the behavior of this system will be divided into three components:

a) The output of the MILES and EWIT transducers, alone, when subject to an applied stress.

b) The vibrational motion of the fence in response to various excitations.

c) The behavior of the coupled system of the fence and transducer.

In what follows, any effect the presence of the transducers may have on the vibrational motion of the fence will be neglected. It will also be assumed that the transducers are securely fastened to the fence so that the motion of the transducers accurately tracks the motion of the fence.

II THE EWIT TRANSDUCER

The EWIT transducer consists of a piece of insulated wire which lies inside of a length of semi-rigid copper tubing. This device may be thought of as a capacitor whose capacitance varies in response to a change in the relative position of the inner and outer conductors; caused by some applied stress. Consequently, the EWIT transducer will respond to relative displacements

of various portions of the transducer.

When connected to a preamplifier, this device may be represented by the equivalent circuit shown in figure 1. With reference to this figure, $C(t)$ is the time dependent capacitance of the EWIT transducer, R is the input impedence of the preamplifier and V_o is the bias voltage which may be supplied either by an external source or by a charge trapped in the transducer.

The charge on the capacitor, $Q(t)$, will be described by the equation

$$V_o = R\frac{dQ}{dt} + \frac{Q}{C} . \tag{1}$$

In order to obtain some basic information regarding the behavior of this circuit it will be assumed that the capacitance varies sinusoidally in response to some applied stress so that we may write

$$C(t) = C_o - eC_o \operatorname{Sin} \omega t . \tag{2}$$

C_o is the initial capacitance of the transducer, e is a small number which will be determined by the magnitude of the applied stress and ω is the angular frequency. With this, equation 1 becomes

$$V_o = R\frac{dQ}{dt} + \frac{Q}{C_o(1 - e\sin \omega t)} . \tag{3}$$

Using the binomial expansion

$$\frac{1}{1 - x} = 1 + x \; .... \; , \tag{4}$$

equation 3 becomes

$$V_o = R\frac{dQ}{dt} + \frac{Q}{C_o}(1 + e \operatorname{Sin} \omega t), \tag{5}$$

which will be valid for small e.

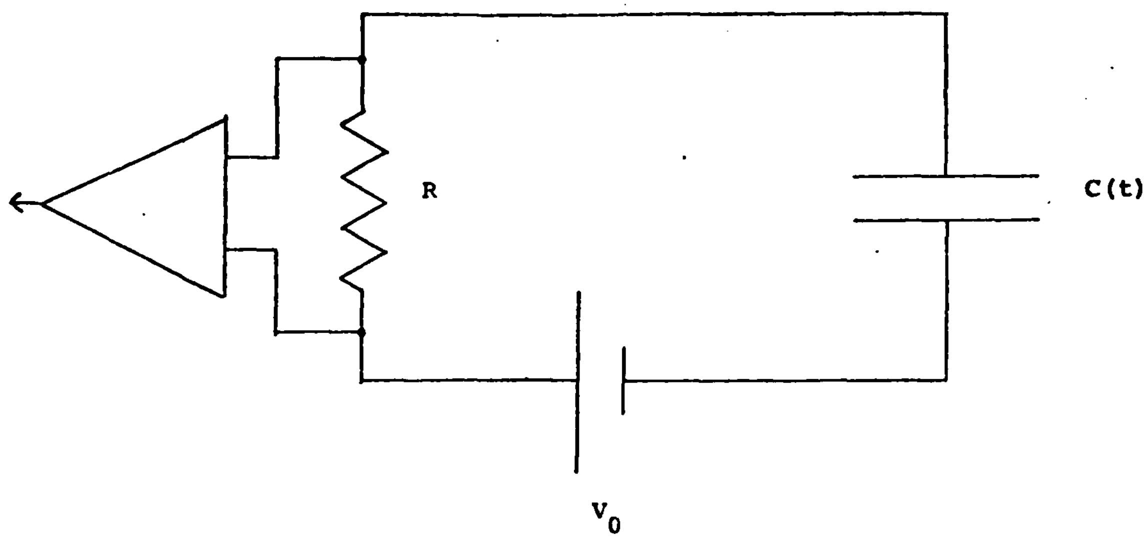

FIGURE 1

Unfortunatly, an exact solution to this equation is not available. However, some information may be extracted regarding two regions of interest.

<u>High Frequencies ($\omega >> RC_o$)</u>

When the rate at which the capacitance varies is high as compared to the RC time constant of this circuit, the charge on the capacitor will not deviate much from its initial value of $Q_o = C_o V_o$. Using this approximation in equation 5 gives

$$V_o = R\frac{dQ}{dt} + V_o(1 + e\,\mathrm{Sin}\,\omega t). \qquad (6)$$

This equation has the solution

$$Q(t) = \frac{V_o e}{R\omega}\mathrm{Cos}\,\omega t + Q_0. \qquad (7)$$

The input voltage to the preamplifier will be given by

$$V_{in} = R\frac{dQ}{dt} = V_o e\,\mathrm{Sin}\,(\omega t + \pi). \qquad (8)$$

This voltage will be independent of the frequency and its peak to peak value will be determined by the magnitude of the applied stress and the bias voltage.

<u>Low Frequencies ($\omega >> RC_o$)</u>

When the rate at which the capacitance varies is small as compared to the RC time constant of the circuit, the rate of change of Q will also be small and so in equation 5 we may neglect the term involving the time derivative of Q. This gives for Q(t)

$$Q(t) = \frac{C_o V_o}{1 + e\,\mathrm{Sin}\,\omega t}. \qquad (9)$$

Using equation 4 gives

$$Q(t) = C_o V_o (1 + e \operatorname{Sin} \omega t). \qquad (10)$$

The input voltage to the preamplifier will be

$$V_{in} = R \frac{dQ}{dt} = e V_o (RC\omega) \operatorname{Sin} (\omega t - \frac{\pi}{2}). \qquad (11)$$

In this case the peak to peak value of the input voltage depends not only on e and V_o but on the frequency as well. For a given stress, the input voltage will decrease with frequency and the rate of this low frequency decrease will be determined by the input impedence of the preamplifier and the capacitance of the EWIT transducer and in practice may be made to occur at quite low frequencies (1Hz.).

These results are applicable when the EWIT is operating in the so-called displacement mode. There is additional output from the EWIT due to the fact that the center wire is free to vibrate inside of the copper tubing. In many cases this mechanism results in a large output from the EWIT at a frequency of about 40Hz. and various harmonics. At times the output at these frequencies will dominate the output at lower frequencies. Unfortunatly this high frequency output is more characteristic of the transducer itself then of the source of the vibrations of the fence.

III THE MILES TRANSDUCER

The MILES transducer may be thought of as a long solenoid which surrounds a nickle alloy, magnetostrictive cable. This transducer has two modes of operation. The first uses the magnetostrictive property of the nickle cable to generate a magnetic field when the cable is stressed. This

produces an output voltage from the solenoid which depends upon the rate of change of the magnetic field produced in the cable. The second mode of operation utilizes the fact that any changes in magnetic fields in the region of the transducer will induce a voltage in the solenoid windings. This second mode will not be discussed any further here.

The behavior of the MILES transducer is complicated by the fact that the direction of the solenoid windings is reversed every 42 inches in order to reduce the sensitivity of the device to distant disturbances. This can give rise to interference effects from signals generated at different locations in the transducer. For the time being these effects will be neglected.

If we assume that for a thin magnetostrictive wire, which lies along the x axis, the magnetic field generated at some point on the wire is proportional to the local change in length of the wire, then the output voltage from the MILES transducer may be related to the motion of the transducer relative to its equilibrium position.

From figure 2, the local change in length of the wire will be given by

$$ds = (dx^2 + du^2)^{\frac{1}{2}} - dx: \qquad (12)$$

u(x,t) is the displacement of the wire from its equilibrium position. The fractional change in length of the wire (strain) will be

$$f(x,t) = \frac{ds}{dx} = (1 + u_x^2)^{\frac{1}{2}} - 1: \qquad (13)$$

the subscript indicates differentiation. The function f(x,t) will give the fractional change in length of the wire as a function of the displacement of the wire from its equilibrium position.

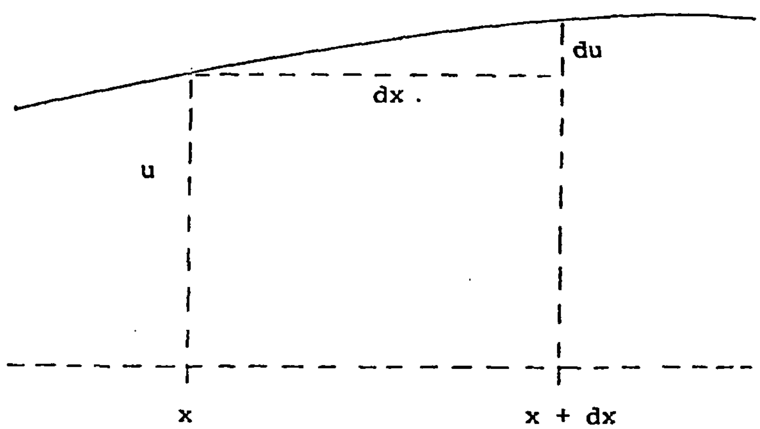

FIGURE 2

Using the binomial expansion

$$(1 + x)^{\frac{1}{2}} = 1 + \tfrac{1}{2}x + \ldots, \tag{14}$$

equation 13 becomes

$$f(x,t) = \tfrac{1}{2}(u_x)^2. \tag{15}$$

This result will be valid for small displacements of the wire.

If we assume that the local magnetic field is proportional to $f(x,t)$, then

$$B(x,t) = k \cdot f(x,t) = \tfrac{1}{2} k \, (u_x)^2 : \tag{16}$$

where the constant k is a characteristic of the magnetostrictive material in the transducer.

The voltage induced in a section of the solenoid of length dx will be

$$dV = n\,a \frac{dB}{dt}\,dx; \tag{17}$$

where n is the number of turns/length in the solenoid and a is the cross-sectional area of the solenoid. Using equation 16 gives

$$dV = \frac{n\,a\,k}{2} \frac{d}{dt} (u_x)^2 dx. \tag{18}$$

The total voltage induced in a section of the solenoid of length $l = x_2 - x_1$ may now be computed from

$$V = \tfrac{1}{2} n\,a\,k \int_{x_1}^{x_2} \frac{d}{dt} (u_x)^2 dx. \tag{19}$$

This formula allows an approximate computation of the output voltage of the

MILES cable once its displacement from the equilibrium position is known as a function of x and t.

In order to take into account the reversal of the solenoid windings every 42 inches, the integral in equation 19, must be computed for each 42 inch section of the MILES and the results for all sections added with the appropriate sign in order to obtain the total output voltage from the transducer. This may lead to cancellation of signals generated at different locations in the MILES.

If the MILES transducer is mounted horizontally, on a vertical fence section of length L and height H, and if the fence is excited at its lowest frequency, then the displacement of the transducer from its equilibrium position may be written as (see section IV)

$$u(x,y) = A \,\mathrm{Sin} \frac{\pi x}{L} \,\mathrm{Sin}\, \omega t \,. \qquad (20)$$

A is a constant which depends on the vertical location of the transducer and ω is the angular frequency corresponding to this mode of vibration.

Using equations 19 and 20, the voltage induced in a section of the MILES cable of length $l = x_2 - x_1$ will be given by

$$V = \frac{n\,a\,k}{2} A^2 \left(\frac{\pi}{L}\right)^2 \frac{\omega}{2} \,\mathrm{Sin}\, 2\omega t \left[\frac{L}{4\pi}\left(\mathrm{Sin}\frac{2\pi x_2}{L} - \mathrm{Sin}\frac{2\pi x_1}{L}\right) + \frac{1}{2}\right]. \qquad (21)$$

From this result it can be seen that the output voltage depends directly on the frequency of vibration of the fence as well as the amplitude. It is also interesting to note that the output frequency from the MILES cable is twice the frequency at which the fence vibrates for this particular type of motion. This effect is due to the nonlinear relationship between the output voltage from the MILES cable and the fence displacement. The term in brackets takes

into account the horizontal location of the section of the transducer relative to the fence.

When the MILES transducer is connected to a preamplifier, its equivalent circuit will be as shown in figure 3. R is the input impedence of the preamplifier, r the internal resistance of the MILES, L the inductance of the MILES and V(t) is the induced voltage in the MILES transducer. As can be seen from this figure, the high frequency response of the MILES will be determined by the L/R+r time constant of this circuit while the maximum input voltage to the preamplifier will be limited by the ratio R/R+r.

IV VIBRATIONAL MOTION OF THE FENCE

Each section of the chain-link fence is mounted on vertical posts which are spaced 10 feet apart. Each of these 10-foot sections of fencing will be considered as an independent vibrating system. There will be some coupling between adjacent sections but any effects due to this will be neglected here.

If we consider only small displacements of the fence from its equilibrium position, assume the fence is of uniform density and that it is under uniform tension, then the displacement of the fence from its equilibrium position will be governed by the wave equation. If we let u(x,y,t) represent the displacement of the fence from its equilibrium position then

$$\frac{1}{a^2} u_{tt} = u_{xx} + u_{yy} : \qquad (22)$$

the subscripts indicate partial derivatives. The wave velocity, a, is given by

$$a = \left(\frac{T}{\rho} \right)^{1/2} \qquad (23)$$

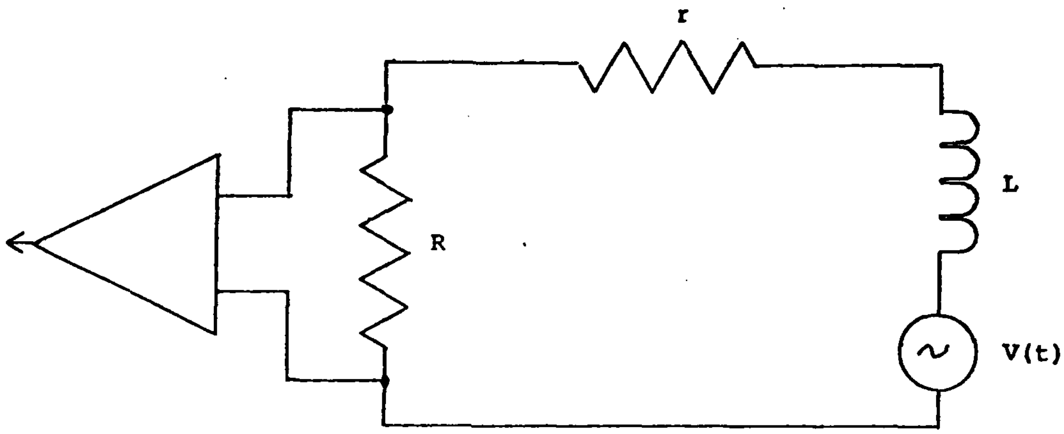

FIGURE 3

where T is the tension/length and ρ is the density (mass/area) of the fence.

If we assume that the displacement of the fence is zero along its perimeter then by the use of separation of variables and a Fourier sum the general solution if equation 22 may be written as

$$u(x,y,t) = \sum_{m,n} A_{mn} \operatorname{Sin}\frac{m\pi x}{L} \operatorname{Sin}\frac{n\pi y}{H} \operatorname{Sin}(\omega_{mn} t + \phi_{mn}). \qquad (24)$$

The integers m and n characterize the various normal modes and the frequency ω_{mn} of each mode is determined by

$$\omega_{mn} = a\left[\frac{m^2}{L^2} + \frac{n^2}{H^2}\right]^{\frac{1}{2}}; \qquad (25)$$

L is the length of each section of the fence and H is the height. The constants A_{mn} and ϕ_{mn} will be determined by the initial conditions of the motion. Using equations 23 and 25, the frequency of vibration for each of the normal modes is

$$f_{mn} = \frac{\omega_{mn}}{2\pi} = \frac{1}{2}\left[\frac{T}{\rho}\right]^{\frac{1}{2}}\left[\frac{m^2}{L^2} + \frac{n^2}{H^2}\right]^{\frac{1}{2}}. \qquad (26)$$

In order to compute these frequencies the tension, T, and the density, ρ, are required.

Density

Each section of the fence is composed of 80 strands of wire each of which has a weight of 9.0 Oz. (.26 Kg.). Each section of the fence has a length of L=3.05M and height H=2.1M. The density of the fence will be

$$\rho = \frac{M}{LH} = 3.19\ \mathrm{Kg/M^2}. \qquad (27)$$

Tension

In order to estimate the tension in the fence we can use information

regarding the force which is required to maintain some static displacement of the fence from its equilibrium position. There is a requirement that, when the fence is installed, a force of 30 Lbs., applied to the center of the fence section shall not produce more than 2.5 inches of deflection. This information may be used to estimate the tension in the fence. The exact shape of the fence section under these conditions is not known but if we assume it to be as shown in figure 4 then an estimate of the tension may be obtained. From figure 4, for equilibrium of the fence we must have

$$F = 2\,T\,H\,\mathrm{Sin}\,\Theta \tag{28}$$

so that

$$T = \frac{F}{2\,H\,\mathrm{Sin}\,\Theta} \,. \tag{29}$$

For small deflections we have

$$\mathrm{Sin}\,\Theta \cong \mathrm{Tan}\,\Theta = \frac{2\,d}{L}. \tag{30}$$

Performing the computations yields an approximate value for the tension of T=761 Newtons/Meter.

Using these values for the density and tension, the frequencies of the normal modes corresponding to values of the integers m and n up to 8 are computed from equation 26 and displayed in table 1. As can be seen from this table, the frequency of the lowest mode is about 4.5 Hz.. This would be the eaisiest mode of the fence to excite and its presence is clearly evident in many of the power spectra obtained from the EWIT transducers.

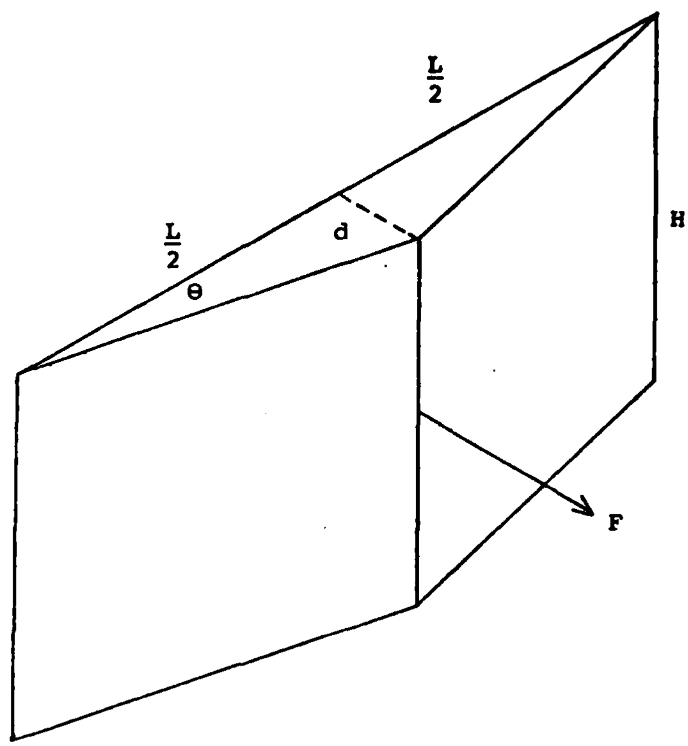

FIGURE 4

TABLE 1

m / n	1	2	3	4	5	6	7	8
1	4.47	6.27	8.46	10.80	13.22	15.67	18.15	20.64
2	7.79	8.94	10.59	12.54	14.67	16.92	19.24	21.60
3	11.33	12.15	13.41	15.00	16.82	18.81	20.92	23.12
4	14.94	15.57	16.58	17.88	19.44	21.18	23.08	25.08
5	18.58	19.09	19.92	21.02	22.36	23.89	25.58	27.41
6	22.23	22.37	23.36	24.31	25.47	26.83	28.35	30.00
7	25.89	26.01	26.87	27.69	28.72	29.93	31.30	33.20
8	29.55	29.88	30.41	31.15	32.07	33.15	34.39	35.77

(all frequencies in Hertz)

V CONCLUSIONS

As discussed in the preceeding sections, there are some basic differences in which characteristics of the fence motion the EWIT and MILES transducers respond to. There are also differences in the frequency response of each of these devices when employed in some type of intruder detection system.

In the displacement mode the peak output voltage from the EWIT transducer is proportional to the displacement of the fence whereas the output from the MILES depends not only on the displacement amplitude but also on the rate at which the surface of the fence is changing shape. The EWIT has a low frequency rolloff which is determined by the capacitance of this device and the input impedence of the preamplifier. This rolloff may be made to occur at a very low frequency by using a preamplifier with a high input impedence. At frequencies above this range, the output of the EWIT should provide a signal whose power spectrum is representitive of the motion of the fence.

In the case of the MILES transducer, there is both a low and high frequency rolloff. For frequencies in between, the output of the MILES will be frequency dependent. Therefore the output signal from the MILES will have a power spectrum which doesnot accurately represent the motion of the fence in that higher frequencies will be more heavily weighted.

At frequencies above 40 Hz., the output signal from the EWIT may no longer be representitive of the vibration of the fence due to the additional vibrational modes of the center wire in this device. The MILES transducer does not suffer from this problem but there are additional complexities due

to the reversal of the windings at 42 inch intervals. This may cause additional distortion of the power spectra which are obtained from the MILES by reducing the output amplitude at some frequencies. This effect could be eliminated by increasing the length of the 42 inch sections to coincide with the length of the fence sections with a resulting increase in sensitivity of the MILES to magnetic fields from distant sources.

The output levels from the EWIT transducer are generally much higher than those from the MILES device. This is a result of the higher sensitivity of the EWIT. However the EWIT device seems to have a non-linear response in some cases in that changes in its output do not seem to represent accurately the corresponding changes in the actual displacement of the fence. This behavior would seem to account for the higher signal to noise ratios which are sometimes observed for the MILES transducer for the same event. The high sensitivity of the EWIT device may not be a desirable feature in fence mounted applications. Table 2 contains a summary af the characteristics of the MILES and EWIT transducers as discussed in this report.

TABLE 2

	MILES	EWIT
Output level	microvolts	millivolts
Power Spectrum	distorted, high frequencies are more heavily weighted	same as fence
Frequency response	poor low frequency response, high frequency rolloff	low frequency rolloff (1 Hz.)
Sensitive to distant events?	yes	not directly
Output modified by device construction?	yes	yes